Enersolve Demonstration Project

Pre-Engineering Assessment

Department of Supply and Services and Energy Mines and Resources Canada

DSS File No.: 02SQ.23440-4-9283
Contract No.: 08SS4-00395
Scientific Authority: Mr. A.C.S. Hayden

Fenco

Fenco

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October 30, 1985

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CANMET Energy Research Laboratories
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Attention: Mr. A.C.S. Hayden

Dear Mr. Hayden:

We are pleased to submit ten (10) copies of our Enersolve project report on the investigation of steel re-heat furnaces operated in the Algoma Steel complex.

We feel our recommendations will lead to significant energy savings and expect Algoma to take action in the very near future.

Thank you for your cooperation and opportunity to work with you on this interesting study.

Yours very truly,

Weldon Thoburn

Weldon Thoburn, P.Eng.,Ph.D.
Manager, Mining and Metallurgy

Enc.

WT/tcs

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MICROMEDIA

46 pp.

October 1985
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ABSTRACT

Fenco Engineers Inc. investigated the combustion efficiencies of steel heat treatment furnaces at Algoma Steel's Superior Limited Partnership as part of an energy conservation study in the Enersolve Demonstration Project program. It was found that about 35 percent of the gross heat input was transferred as sensible heat to te steel.

The following methods to improve the efficiency were evaluated:

i) furnace sealing and draft control,
ii) recycling flue gas between furnaces operating in tandem, and
iii) a computerized supervisory control system.

Paybacks ranged from about two to more than four years.

RÉSUMÉ

Fenco Engineers Inc. a évalué le rendement des fours à traitement thermique servant à la fabrication de l'acier pour la Superior Limited Partnership, propriété d'Algoma Steel, dans le cadre d'une étude portant sur la conservation de l'énergie et faisant partie du Programme fédéral de démonstration du chauffage solaire dans les secteurs commercial et indus- triel. Le chauffage réel de l'acier représentait 35 % de l'apport de chaleur brut.

Comme suite à cette étude, la firme a recommandé des mesures visant à améliorer le rendement actuel, soit:

i) obturation du four et installation d'un dispositif de réglage du tirage;

ii) recyclage du gaz de carneau se trouvant entre deux fours fonctionnant en tandem;

iii) installation d'un dispositif informatisé de contrôle des opérations.

On estime que cette installation sera rentable dans un délai de deux à quatre ans environ.

1.0 SUMMARY

Within the framework of the Enersolve series of energy conservation demonstration projects, Fenco Engineers studied the operation of steel heat treatment furnaces at Superior Limited Partnership, part of the Algoma Steel complex at Sault Ste. Marie, Ontario.

The two furnaces evaluated are natural gas fired re-heaters* each operating at about 150 GJ/h processing seamless pipe. Site measurements determined flue gas compositions, temperatures and pressures; this data, combined with fuel rates and steel throughputs, yielded a heating efficiency of approximately 35 percent.

Flue gas compositions of about 18 percent oxygen indicate that the excess air to each furnace totals 600 percent, most of which apparently ingresses through various ports and openings due to unregulated furnace draft.

The following options were reviewed as possible means of improving fuel use and heating efficiencies:

i) Sealing of the furnace shells and installing a draft control system based on temperature and oxygen measurements to minimize ingress air.

ii) Recycling flue gas from the hotter quench furnace through the pre-heat furnace. This approach also lends itself to heating load distribution optimization between the two furnaces.

iii) Installation of a furnace supervisory computer control system after the above efficiency improvement program has been implemented.

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*The two re-heaters are designated the pre-heat and quench furnaces and operate in series.

Table 1 outlines the costs and simple paybacks for the various improvements considered. The fuel savings are conservative estimates based on our experience and those of other designers in the industry([3]).

The most attractive option is the simple measurement and control of flue gas to minimize ingress air.

Recycling flue gas from the quench to pre-heat furnace is not attractive unless a dramatic increase in the quench furnace flue gas temperature can be demonstrated. A complex computer control system could be evaluated after the simpler improvements are implemented and evaluated.

TABLE 1

SUMMARY OF ENERGY CONSERVATION SCHEMES AND COSTS

Option Description	Capital Cost ($)	Fuel Savings ($/yr)	Simple Payback (years)	Cost for 9 Month Monitor** ($)
Shell Sealing and Draft Control	15,200*	9,840	1.5	15,000
Recycling Off-gas from the Quench Furnace Example***	150,000	34,970	4.3	15,000
Supervisory Computer Control	418,000	98,400	4.2	20,000

* Per furnace

** Monitoring by engineering group external to plant operations.

*** Assuming a Quench Furnace excess Air of 100 Percent as discussed in Section 4.2

2.0 INTRODUCTION

In February 1985 Fenco Engineers Inc. (Fenco) was awarded an energy conservation study under the auspices of CANMET's Enersolve Demonstration Project.* Fenco, in co-operation with Algoma Steel's Energy Management Department, evaluated the on-going operation of two steel heat treatment furnaces at the Superior Limited Partnership tube mill. The mill is located in the Algoma Steel Corp. complex at Sault Ste. Marie, Ontario.

Process data collected formed the basis for the following:

i) estimates of system heating efficiencies, and

ii) the development of retrofit concepts

This report outlines the analysis of the plant test measurements, and discusses methods to improve fuel efficiencies and costs associated with those improvements.

* Department of Supply and Services Contract No. 02SQ.23440-4-9283-4

3.0 ASSESSMENT OF PRE-HEAT AND QUENCH FURNACE OPERATIONS

3.1 Background Discussion of Heat Treatment Furnaces Operation

A variety of grades of seamless pipe produced at Superior Limited Partnership are heat treated to produce required mechanical properties. Heating prior to water quenching is carried out in two furnaces operating in tandem designated the pre-heat and quench furnaces. Historically, production demands and the desire for a longer soak time exceeded the heating capability of the quench furnace which prompted the installation of pre-heat furnace around 1980. A schematic arrangement of the furnaces and flues is shown in Figure 3.1. The hardened pipe is tempered in the draw furnace also shown in Figure 3.1. The draw furnace operation is beyond the scope of this study.

Steel pipe, fed to the pre-heat unit, usually retains heat from the forming operation and enters at about 370°C. However, cold pipe stock is also treated.

Pipe progress through the furnaces on walking beam assemblies. The pre-heat furnace typically heats steel to temperatures ranging from 650 to 760°C. Temperatures in the quench furnace range from about 870 to 950°C. The temperature difference between the two furnaces averages about 160°C. Flue gases from the two furnaces currently exhaust into two separate flue and stack gas trains. Both furnaces have flue gas exits beneath the working elevations of the furnaces requiring that off-gases flow down into a header and along a sub-floor flue. The sub-floor flue length is longer in the case of the pre-heat furnace.

Natural draft is provided by stacks servicing the furnaces. Draft control is set by dampers which are positioned from the furnace control rooms. Attempts to automate the draft control were unsatis-

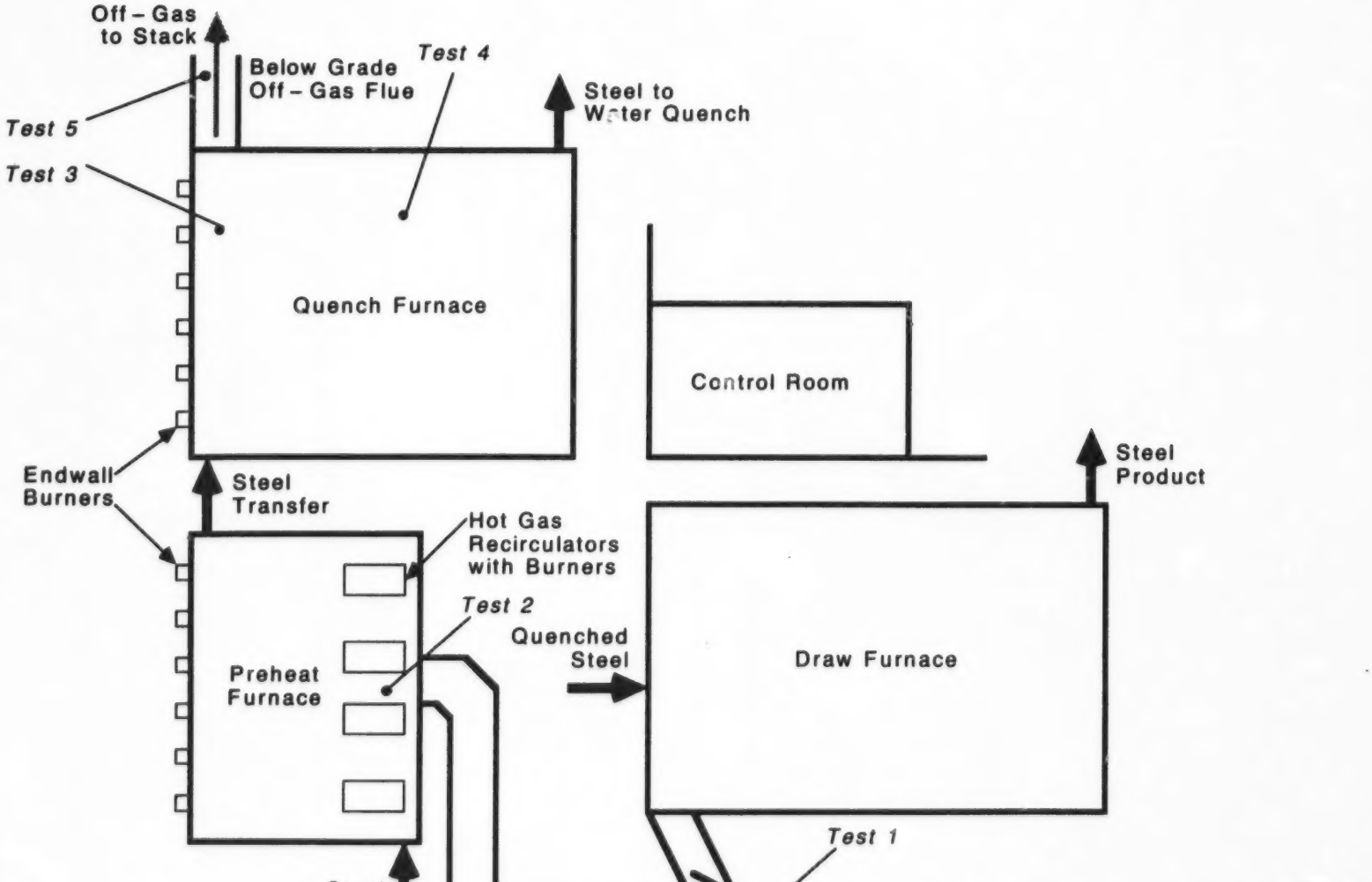


Figure 3.1

Schematic Arrangement of Heat Treatment Furnaces and Flues

factory due to a poor control circuit design which responded erratically to changing furnace operating conditions. Flue dampers opened completely at times, chilling the furnaces and producing "off-spec" pipe. As a result, manual positioning has been adopted.

Flue gas temperature and composition are not monitored. Operators set the dampers using an in-furnace draft indication, operating temperatures and visual observations.

3.2 Furnace Operations

Summary descriptions of the furnaces and their operations are outlined in Table 3.2-1. The two furnaces currently operate at less than half their design firing rate. Fuel costs totalled $1.76 million in 1984. A summary of the testwork and field measurements discussed in Appendix 1 is shown in Table 3.2.2.

Off-gas oxygen and temperature measurements show considerable excess air ingresses into the furnaces. Tramp air appears to be principally in-leaking through large stock feed and discharge openings near the off-gas exhaust areas where the draft is greatest. Other smaller openings around the mechanical stock roller conveyors, for example, also permit air ingress. Burners used in the furnaces were designed for heat treat and melting furnaces by the North American Mfg. Co. These units can operate over a wide range of excess air. The contribution of excess air in the flue gas from the burners is not known since the air flowrate is not measured. However, mid-furnace freeboard gas compositions of 3 to 5 percent measured in the quench furnace suggest the burner contribution is small compared to ingress air leakage.

TABLE 3.2-1

SUMMARY OF HEAT TREATMENT FURNACE DESCRIPTIONS AND OPERATING DATA

Item	Furnaces: Pre-heat	Furnaces: Quench
Manufacturer	Midland Ross	Salem
Design Data*		
Natural gas (m^3/hr)	3984	4150
Gross heat input (GJ/h)	151.9	158.2
(10^6 BTU/h)	144	150
No. of endwall burners	24**	48***
No. of circulating burners	12	0
O_2 in off-gas (vol%)	2	
Recent Operations		
Steel feed rate (tph)	73	
Natural gas (m^3/hr)	1133	1048
Gross heat input (MJ/h)	43.2	40.1
(10^6BTU/h)	41	38
(millions BTU/ton steel)	1.56	
Forced Draft Fan (m^3/h^{-1})	53760	53760
Calc. heating effeciency (%)	35	
O_2 in off-gas (vol%)	18	18
Off-gas temperature (°C)	290	315
Annual (1984) Gas Use (10^6 BTU)	205044	160914
($)	984000	772400

* Available design data limited to information shown in this table.

** North American Mfg. Co. type 4422-8A.

*** North American Mfg. Co. type 123-8B and 123-7.

TABLE 3.2-2

SUMMARY OF FURNACE MEASUREMENTS

Test No.	Furnace	Sample	Measurements		
			% O_2 (dry)*	°C	draft (cm wc)
1	Pre-heat and Draw	Mixed Flue Gases	15.5	354	-2.22
2	Pre-heat	Off-gas	18	290	-0.51
3	Quench	Freeboard Near Off-gas Outlet	12.5	-	-
4	Quench	Central Freeboard Zone	2.5 to 5	-	-
5	Quench	Flue gas	18	315	-

* measured with a portable Teledyne oxygen analyser.

A heat balance for the pre-heat furnace operation in April 1985 is outlined in Table 3.2-2. The quench furnace balance is described in Section 3.4. Based on the process data, heat directed to the steel charge is about 35 percent of the gross fuel heat input. About 60 percent of the gross heat is contained in the dry combustion gases. The off-gas oxygen concentration of 18 percent corresponds to a total air rate of 700 percent or 600 percent excess air. An unaccounted of 11.7 percent excess heat in the products is shown in Table 3.2-2. Using the flue gas composition and temperature as an alternate method to estimate the efficiency (1) of furnace operations can, in this instance, yield a low estimate.

The ingress air flow patterns are inhomogeneous in the furnaces studied. Tests 3,4 and 5 in Table 3.2-2 illustrate the increased oxygen content of the gases near the off-gas outlet and in the flue compared with the central heating zone of the furnace.

The change in heat in the steel pipe in Table 3.2-3 indicates an efficiency of at least 25 percent. Appendix IV shows an efficiency of about 10 percent using the flue gas data without regard for the way tramp air enters the furnaces.

A summary of the heat distribution related to the fuel input is shown in Table 3.2-4.

The capacity of the pre-heat furnace sub-floor flue was evaluated based on draft and temperature measurements described in Appendix I - Test 1. The parameters used are as follows:

Flue Length (m)	28
Temperature (°C)	354
Flue Gas (Am^3s^{-1})	86.8

TABLE 3.2-3

PRE-HEAT FURNACE HEAT BALANCE*

Materials	kg/h	kJ/kg	°C	GJ/h	% Input
Input					
Natural Gas (HHV)	-			44.4	74.5
Steel Feed**	72,727	209.8	371	15.3	25.5
Air			15.5	0	
Total				59.7	100
Output					
Combustion Gases					
$N_2 + O_2$**	92,230	282	290	26.1	43.6
CO_2	2,198	263	290	0.5	1
H_2O	1,735	531	290	1.0	7.1
H_2O Evaporation	1,735	2,450	-	4.2	1.5
Steel Out	72,727	422	704	30.7	51.4
Shell + Radiation Loss	-	-	-	4.2	7.1
Unaccounted	-	-		-7.0	-11.7
Total				59.7	100

* Reference state 15.5°C.

** Equivalent to 600% excess air and a flue gas containing 18% O_2 and the natural gas fuel rate shown in Test 2, Appendix I.

*** Steel rate is from production data and temperatures measured using a portable infra-red thermometer.

TABLE 3.2-4

SUMMARY OF FUEL GROSS HEAT INPUT DISTRIBUTION FOR THE PRE-HEAT FURNACE OPERATION

Loss Item	
Dry Off-gas	59.9
Hydrogen Loss	11.6
CO Loss	0
Shell and Unaccounted	-6.2
	65.3 *

* Balance to steel is 34.7 percent.

Flue Area (m^2)	0.68
Flue Gas Density (kg/m^3)	0.56
Draft (cm w.c.)	2.

Pressure loss along the flue to the stack was calculated to be 0.015 cm w.c. which indicates the flue system has spare gas handling capacity at current levels of production.

Draft at the stack base was calculated to be approximately 2 cm w.c. confirming the flue pressure drop estimate.

4.0 ENERGY CONSERVATION AND RETROFITS

4.1 General Approach

Fuel consumption in heat treatment furnaces varies with many factors including:

i) The steel feed rate, incoming temperature, geometry, hearth cover,
ii) Combustion conditions, excess air, furnace draft,
iii) Construction features of the furnace such as number of heating zones, wall insulation, door structures, and
iv) Waste heat recovery systems.

Consideration is given some of the above, especially simple modifications, which can be implemented and assessed relatively easily. The improvements can be considered a series of projects which are interdependent.

4.2 Shell Sealing and Draft Control - Phase 1

Flue gas measurements discussed in Section 3 indicate that openings in the furnace shell (doors etc.) and a manually controlled draft system tend to promote tramp air ingress and cold flue gases. For example, ingress air flowing through the pre-heat furnace exit door would have an undesirable cooling effect on steel leaving the furnace. Flue gas exits at the hearth level which may tend to alleviate the cooling effect somewhat. Figure 42723-SK1 illustrates the general arrangement of the furnaces and the proximity of the steel charging doors to the off-gas manifolds located below grade.

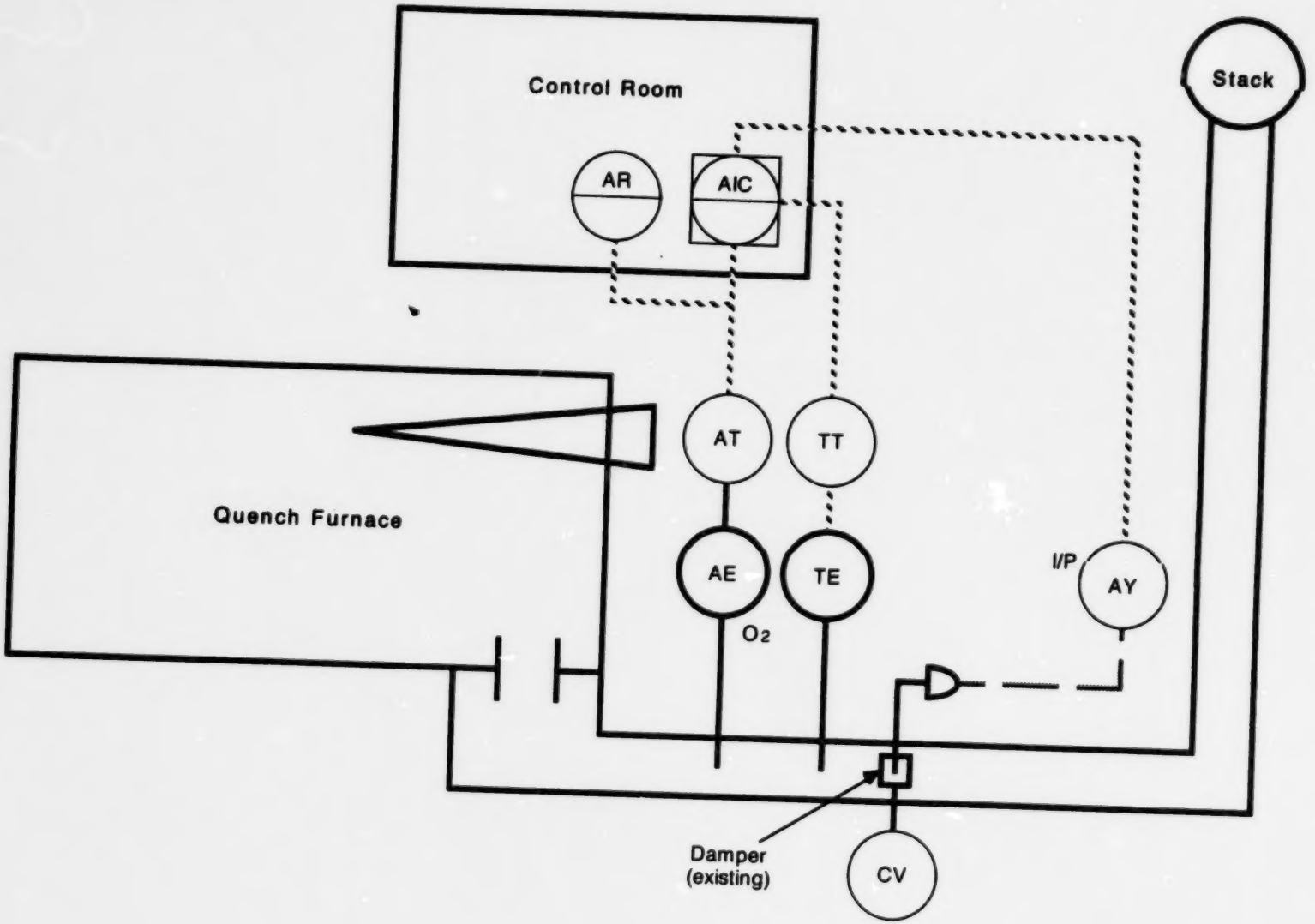


Figure 4.2 – 1

Schematic of Off – Gas Measurements for Draft Control

Relatively simple instruments can be added to monitor flue gas conditions. Figure 4.2-1 shows an oxygen meter and thermocouple added to the quench furnace flue with results displayed in the furnace control room.

With these aids, furnace draft can be optimized to minimize air ingress while ensuring combustion products are vented properly. Further ingress air reduction can be achieved by sealing ports and openings that lend themselves to closure. This, of course, necessitates that steel stock enters and exits freely and any furnace parts that received cooling air by design are not starved. This sealing work could run concurrently with the draft setting program as part of the routine furnace maintenance.

Once these modifications are complete the heat available in the quench furnace off-gas for recovery schemes can be calculated.

Costs for the instruments and their installations are as follows:

Quench Furnace Draft Control Instrument Costs

Item	$
Oxygen probe and thermocouple (installed)	8,200
Wiring, Power, Panel Preparation and Indicator (Controller-Taylor-MOD30)	4,000
Engineering	3,000
Total	15,200

Fuel savings are difficult to forecast, however, a one percent savings* represents a simple payback of about 1.5 years. A reduction in ingress to some other assumed value could also be used to estimate

*This is equivalent to less than a 5 percent reduction in ingress air which should easily be attainable.

the fuel savings. The conclusion that this is a very cost effective scheme would remain unchanged.

If the improvements demonstrated following installation of the draft controls on the quench furnace are sufficient to warrant further evaluation of waste heat recuperation, a similar scheme may be justified for the pre-heat furnace.

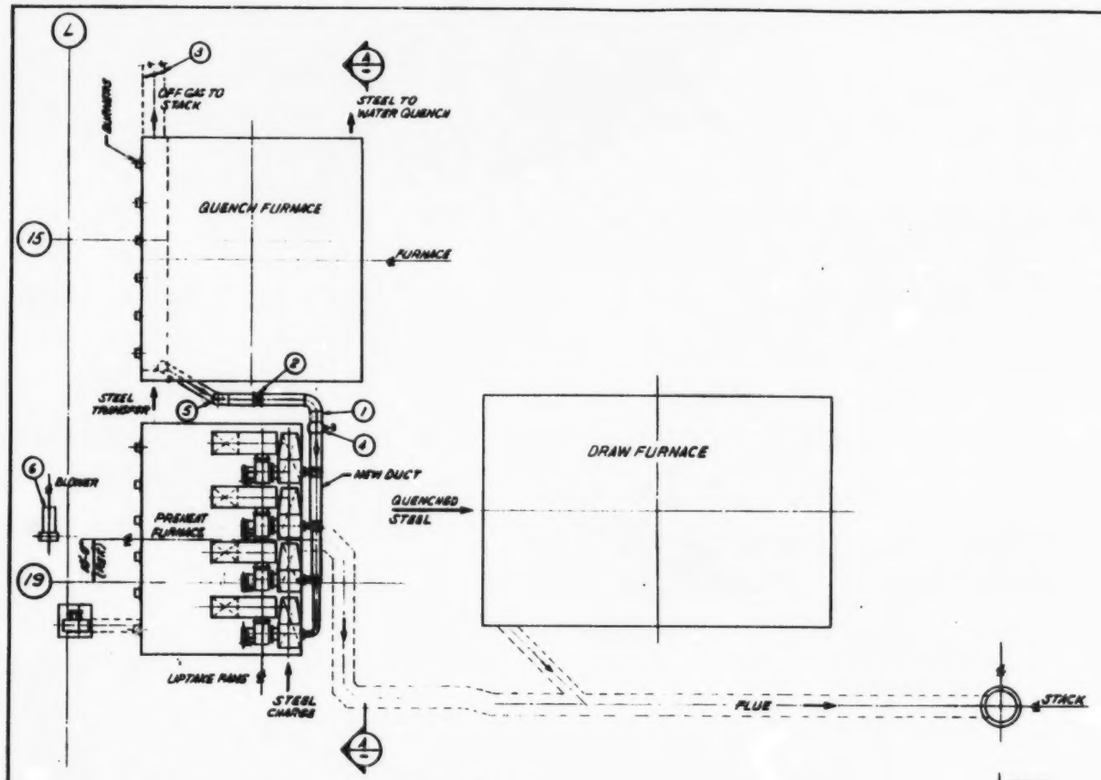
Should flue gas oxygen and temperature measurements improve draft damper setting, the indicator controller can be put into service as a controller.

4.3 Recycling Off-Gas From The Quench to The Pre-Heat Furnace - Phase II

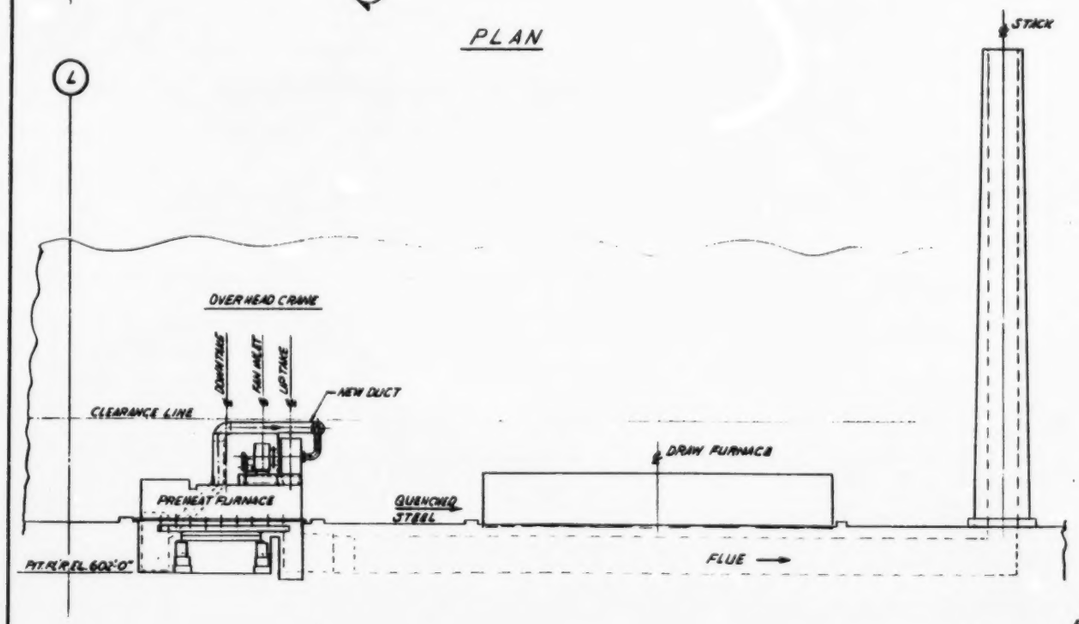
In this example scheme, it is assumed the quench furnace can be modified as discussed in Section 4.2 and the excess air reduced from about 600 to 100 percent yielding an off-gas at 1120°F (604°C) for recycle to the pre-heat furnace. A general arrangement of the furnaces and ducting is shown in Figure 42723-SK1.

A heat balance for this improved quench furnace operation is shown in Table 4.3-1. A lower excess air could be substituted, however the 85 percent reduction selected represents a significant improvement. It should be noted that 2 percent oxygen in the combustion products was adopted for the original design[2] of the pre-heat furnace. This is equivalent to about 10 percent excess air which is markedly less than observed values. Recycle gases hotter than 1120°F may be possible.

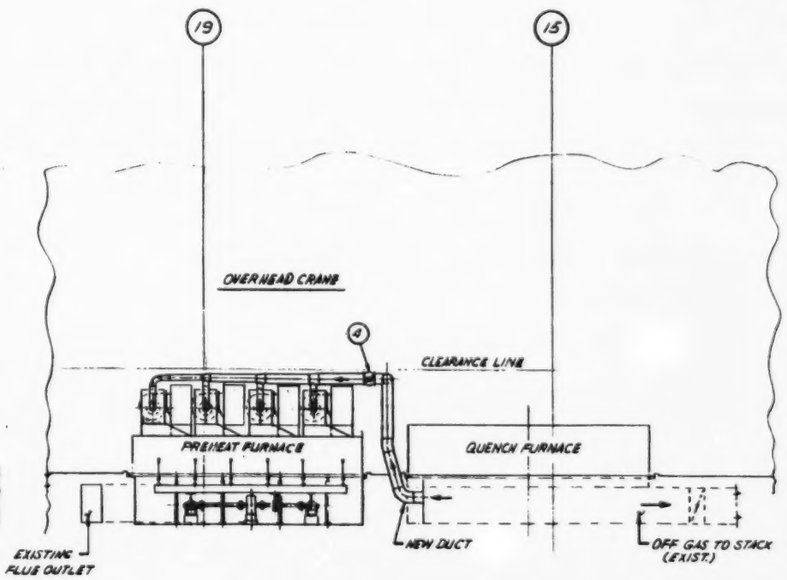
For this example, recycle gas flows from the quench furnace off-gas header to the inlet side of the recirculating fans on the pre-heat furnace. This is the best route due to the relatively low temperature of the off-gas. A simpler gas route could be established connecting



PLAN



ELEVATION



SECTION A

NOTES AND REFERENCES

1. HOT GAS RECYCLE DUCTING REFRACTORY LINED WITH CASTABLE TO GIVE ABOUT 36" Ø OPENING. EXTERNAL INSULATION & CLADDING REQUIRED.
2. EXPANSION JOINT DETAILS AND SUPPORTS NOT ALL SHOWN.
3. EXISTING QUENCH FURNACE DAMPER SHOWN DIAGRAMATICALLY
4. HOT GAS FLOW CONTROL VALVE
5. EXACT POSITION OF EXCAVATION FOR DUCTING ROUTE BELOW GRADE TO BE DETERMINED BY FIELD MEASUREMENTS
6. FOR SIMPLICITY, EXISTING AIR AND GAS SUPPLY PIPING SYSTEM IS NOT SHOWN.

NO	REVISION	DATE	BY

DWG DATE	SEPT 12-85
DRAWN BY	S. BACANIN
CHECKED BY	
DEPT HEAD	
ORIENTATION	NOMINAL
PROJ MGR	A. KURTIS
ISSUE DATE	SEPT. 13-85
ISSUED FOR	PRELIMINARY

PROJECT TITLE
ENERSOLVE DEMONSTRATION PROJECT - ALGOMA'S SUPERIOR LTD. PART. TUBE MILL

DRAWING TITLE
HOT GAS RECYCLE DUCTING - QUENCH FURNACE TO PRE-HEAT FURNACE

Fenco
FENCO ENGINEERS INC.

SCALE 1/16"-1'-0"

0 1 2 3 INCHES

DRAWING NUMBER 427 - SK1

REV A

TABLE 4.3-1

QUENCH FURNACE HEAT BALANCE*

Materials	kg/h	kJ/kg	°C	GJ/h	% Input
Input					
Natural Gas (HHV)	-			37.4	54.9
Steel Feed	72,727	210	704	30.7	45.1
Air			15.5	-	
Total				68.1	100
Output					
Combustion Gases					
N_2**	17,668	636	604	11.2	16.5
$CO_2 + O_2$	4,487	597	604	2.6	3.9
H_2O	1,460	1,186	604	1.7	2.5
H_2O Evaporation	1,460	1,450	-	3.6	5.3
Steel Out	72,727	599	915	43.5	63.9
Shell + Radiation Loss	-	-	-	5.4	7.9
Unaccounted	-	-		0	-
Total				68.1	100

* Reference state 15.5°C.

** Equivalent to 100% excess air and a flue gas containing about 4% O_2.

the quench furnace outlet to the north wall area of the pre-heat furnace, however, the cool off-gas will not provide heating assistance in this hotter zone.

Recycling flue gas to the bank of recycle heaters produces a heating benefit based on the heat balances shown in Tables 4.3-2 and 4.3-3. Without recirculation, fuel to the convection/circulation zone is assumed to be 33 percent of the furnace feed. Steel and gas exit at 1050°C from the convection zone of the pre-heat furnace.

Introducing recycle flue gas from the quench furnace reduces the pre-heat furnace fuel requirement by only 0.92 MMBTU/h (0.97 GJ/h) due to the small temperature difference between the recycle and circulating gases. The value of this gas savings totals $34,970 per year over 330 days of operation.

This relatively small savings associated with recycling 1120°F (604°C) gas to the pre-heat furnace illustrates the critical importance of the grade of recycle flue gas.

A preliminary cost estimate for routing the quench furnace gases to the pre-heat furnace is shown in Table 4.3-4. The scheme yields a simple payback of 4.3 years. An increase in the recycle flue gas temperature would of course enhance the benefits of this scheme.

In attempting to optimize fuel use, it may be worthwhile to evaluate the shifting of heating load between the two furnaces. This could be carried out on an incremental load shift basis to ensure product quality is maintained. The principal concern by operations would be the reduced life of the quench furnace at higher temperatures and the product soak time at temperature. At very low feed rates, it may be possible to curtail the pre-heat furnace operating. Details of furnace management options are beyond the scope of this report.

TABLE 4.3-2

PRE-HEAT FURNACE CONVECTION ZONE HEAT BALANCE*

Materials	kg/h	kJ/kg	°C	GJ/h	% Input
Input					
Natural Gas (HHV)	-			14.8	49
Steel Feed	72,727	210	371	15.3	51
Air			15.5	0	
Total				30.1	100
Output					
Combustion Gases					
N_2**	6985	597	566	0.41	1.4
$CO_2 + O_2$	939	559	566	0.52	1.8
H_2O	577	1,112	566	0.65	2.1
H_2O Evaporation	577	2,450	-	1.4	4.6
Steel Out	72,727	343	566	24.96	82.9
Shell + Radiation Loss	-	-	-	2.1	7.0
Total				30.1	100

* Reference state 15.5°C.

** Equivalent to 20% excess air and a process gas containing 4% O_2.

TABLE 4.3-3

PRE-HEAT FURNACE WITH RECYCLE GAS BALANCE*

Materials	kg/h	kJ/kg	°C	GJ/h	% Input
Input					
Natural Gas (HHV)	-			13.8	30.8
Steel Feed	72,727	210	371	15.3	34.1
Air			15.5	0	
Recycle Gases			604	15.6	35.1
Total				44.7	100
Output					
Combustion Gases	2,214		566	1.6	3.6
Recycle Gases	23,636		566	14.7	32.8
Evap. H_2O	577	2450	-	1.4	3.1
Steel Out	72,727	422	566	25.0	55.8
Shell + Radiation Loss	-	-	-	2.1	4.7
Total				44.7	100

* Reference state 15.5°C.

TABLE 4.3-4

SUMMARY OF COSTS FOR RECYCLING QUENCH FURNACE FLUE GAS THROUGH THE PRE-HEAT FURNACE

		1000 $
Excavation & Tie-Ins		5
Refractory Lined Duct with Expansion Joints between Furnaces		61.9
Valve and Instrumentation*		37
Engineering		22.5
Allowance for Retrofit (15%)		22.5
TOTAL		148.9
	Say	$150,000

* Includes damper to control gas flow to the recirculation fans and thermocouples. Controls and displays are in the preheat furnace control room.

A mathematical model for this retrofit scheme could be developed, however, a field trial approach could better utilize available operation's experience.

4.4 Furnace Supervisory Control Approach and Other Options

Based on the foregoing discussion, the current re-heat furnace operations appear to be prime candidates for energy conservation improvements. As noted above, a basic program of furnace sealing and fuel conservation should first be developed. Once the operations are tuned and tweeked, it should then be possible to evaluate more complex and comprehensive furnace management systems.

An example of these control systems is the supervisory computer control system such as the one proposed for Algoma's Number 2 Seamless Mill roatary hearth furnace. Italimpianti[3] and others have developed control systems integrating process data and a mathematical model which together are expected to optimize productivity and fuel consumption. A schematic outline is shown in Figure 4.4-1.

Application of a system as sophisticated as this is not recommended as a first step to improve furnace efficiencies. Instead, it would be a method to consider once simpler program benefits are exhausted. The cost information in Table 4.4-1 presents approximate costs for the installation of a supervisory control system such as the Italimpianti product. Costs can be compared to those in Section 4.2 which describe a very basic scheme to improve combustion efficiencies. The two can be considered to represent the range of costs covering rudimentary and elegant furnace control methods. A fuel savings of 10 percent is not uncommon following installation of these computerized control systems together with other benefits. A conservative 10 percent fuel savings was used for the simple payback which is 4.2 years.

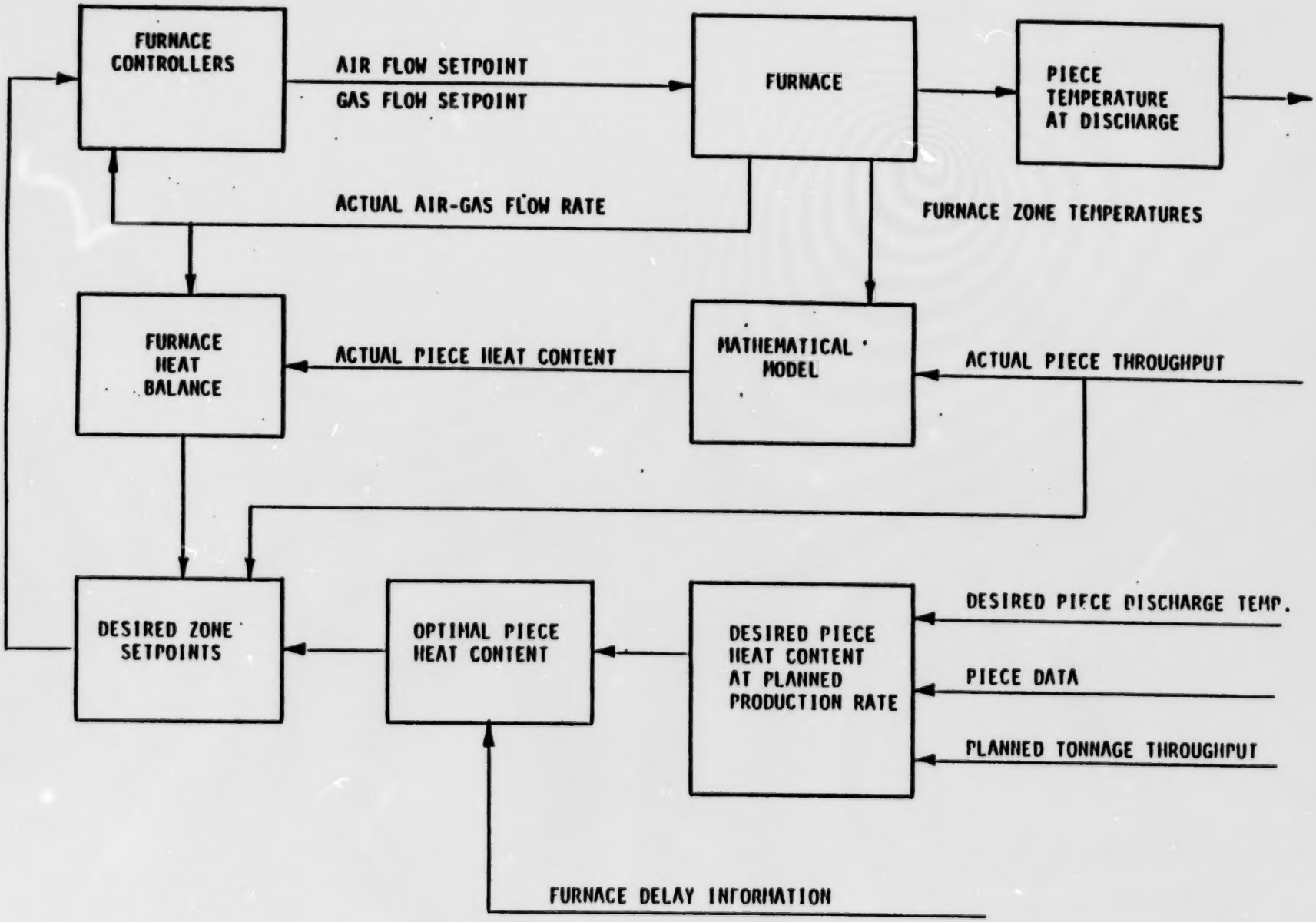


FIGURE 4.4-1 FURNACE CONTROL BY ON-LINE MATHEMATICAL MODEL

TABLE 4.4-1

COSTS FOR INSTALLATION OF A SUPERVISORY CONTROL SYSTEM

Cost Area	Cost
Host Computer PDP 11/785 adaptations	5,000*
Supervisory System including PDP 11/84 controllers, displays, printer, networking, and software installed	300,000
Additional furnace measurements and controls - installed and tied into supervisory system	50,000
Engineering	63,000
TOTAL	418,000

* Assumes hardware is available and software in use is compatible.

Other capital intensive schemes could be considered. Waste heat boilers and pre-heating of combustion air are examples of retrofit schemes which require major investments and physical changes and were not analysed since much simpler and inexpensive programs can be exploited beforehand.

REFERENCES

(1) Friedrich F.D. and Hayden A.C.S., Combustion Handbook for Canadian Fuels Vol 2, Mines Branch monog. 879, 1973.

(2) Communication with Frank Vereecke of Midland Ross' Furnace Design Group.

(3) Italimpianti Inc., Supervisory Computer Control Option for No. 2 Seamless Mill Rotary Hearth Furnace, May 1985.

(4) Hayden A.C.S., Letter to Fenco, Aug. 19, 1985.

APPENDIX I

SUMMARY OF FURNACE OPERATING DATA AND TEST MEASUREMENTS

APPENDIX I

SUMMARY OF FURNACE OPERATING DATA AND TEST MEASUREMENTS

Test No. 1 - April, 1985

Flue gases were monitored downstream of the mixing junction of off-gas from the pre-heat and draw furnaces. Sampling locations are shown in Figure 3.1. Furnace natural gas fuel rates were: Draw Furnace 75,000 CFPH (2124 m^3/h) and the Pre-Heat Furnace 40,000 CFPH (1133 m^3/h). Natural gas volumes are recorded on plant fuel use monitors.

Draft for the furnaces is provided by stacks for the draw and pre-heat furnaces and controlled by dampers which are set by the operators. The dampers were 30 percent open in each case.

Flue gas samples contained 15.5 percent oxygen (dry basis) on average at a temperature of 354°C. Draft in the flue was -2.22 cm W.C. (-0.8" W.C.).

These measurements establish data on flue conditions for estimates of the capacity of the flue leading to the stack.

Test No. 2 - April, 1985

Measurements of off-gas under the pre-heat furnace near the outlet to the flue were carried out to determine the off-gas volume from the pre-heat furnace and the apparent overall heating efficiency. Fuel consumption was 42,000 CFPH during the test.

Off-gas sampled contained 18 percent oxygen at 290°C. Draft at the sample point was -0.51 cm W.C.

Test No. 3 - April 23, 1985

Quench furnace freeboard gas was sampled near the off-gas outlet. Oxygen in the gas was 12½ percent. The furnace was fired at about 37,000 CFPH (1048 m^3/h)of natural gas which is approximately 25 percent of its rated capacity.

This test established a furnace freeboard gas composition.

Test No. 4 - April 23, 1985

The quench furnace mid-section atmosphere was analysed to determine if the oxygen in the off-gas ingressed principally near the off-gas outlet. The furnace atmosphere at this point contained 2.5 to 5 percent oxygen indicating ingress air tends to enter more at the flue gas exit.

Test No. 5 - April 23, 1985

The composition and temperature of the flue gas from the quench furnace was measured to identify the amount of gas and heat that could be recycled to the pre-heat furnace.

The quench furnace was firing 37,000 CFPH of natural gas producing a 315°C off-gas containing 18 percent oxygen. The recorded furnace operating temperature was about 882°C (1620°F).

APPENDIX II

UNIT RATES USED IN CALCULATIONS

APPENDIX II

Item	Unit Rates Imperial	Metric
Natural Gas Properties		
Gross Heat Value (BTU/SCF*)(MJ/m^3)	1024	38.3
Net Heat Value (BTU/SCF)(MJ/m^3)	923	34.5
Combustion Air (ft^3/ft^3 gas)(m^3/m^3)	9.62	9.62
($lb/10^6$ BTU)(kg/MJ)	714.9	0.31
Combustion Products		
CO_2($lb/10^6$ BTU)(kg/MJ)	115.3	0.05
N_2 ($lb/10^6$ BTU)(kg/MJ)	551	0.24
H_2O ($lb/10^6$ BTU)(kg/MJ)	91	0.04
Excess Air - for each 20%([1])		
Air ($lb/10^6$ BTU) (kg/MJ)	142.9	0.065
Natural Gas Cost($/$10^6$ BTU)($/GJ)	4.80	4.55

* Standard condition is 60°F (15.5°C) and 1 atm.

APPENDIX III

HEAT BALANCE CALCULATIONS IN IMPERIAL UNITS

TABLE 3.2-3B

PRE-HEAT FURNACE HEAT BALANCE*

Materials	lb/h	BTU/lb	°F	MMBTU/h	% Input
Input					
Natural Gas (HHV)	-			41.9	74.5
Steel Feed	160,000	90	700	14.4	25.5
Air			60	0	
Total				56.3	100
Output					
Combustion Gases					
$N_2 + O_2$**	202,906	121	554	24.6	43.6
CO_2	4,836	112.8	554	0.5	1
H_2O	3,817	227.6	554	0.9	7.1
H_2O Evaporation	3,817	1,051	-	4	1.5
Steel Out	160,000	181	1,300	29	51.4
Shell + Radiation Loss	-	-	-	4	7.1
Unaccounted	-	-		-6.6	-11.7
Total				56.3	100

* Reference state 60°F.

** Equivalent to 600% excess air and a flue gas containing 18% O_2

TABLE 4.3-1B

QUENCH FURNACE HEAT BALANCE*

Materials	lb/h	BTU/lb	°F	MMBTU/h	% Input
Input					
Natural Gas (HHV)	-			35.3	54.0
Steel Feed	160,000	181	1,300	29	45.1
Air			60	-	
Total				64.3	100
Output					
Combustion Gases					
N_2**	38,871	273	1,120	10.6	16.5
$CO_2 + O_2$	9,871	256	1,120	2.5	3.9
H_2O	3,212	509	1,120	1.6	2.5
H_2O Evaporation	3,212	1,051	-	3.4	5.3
Steel Out	160,000	257	1,680	41.1	63.9
Shell + Radiation Loss	-	-	-	5.1	7.9
Unaccounted	-	-		0	-
Total				64.3	100

* Reference state 60°F.

** Equivalent to 100% excess air and a flue gas containing about 4% O_2.

TABLE 4.3-2B

PRE-HEAT FURNACE CONVECTION ZONE HEAT BALANCE*

Materials	lb/h	BTU/lb	°F	MMBTU/h	% Input
Input					
Natural Gas (HHV)	-			13.9	49
Steel Feed	160,000	90	700	14.4	51
Air			60	0	
Total				28.4	100
Output					
Combustion Gases					
N_2**	1,535	256	1,050	0.39	1.4
$CO_2 + O_2$	2,067	240	1,050	0.5	1.8
H_2O	1,269	477	1,050	0.61	2.1
H_2O Evaporation	1,269	1,051	-	1.3	4.6
Steel Out	160,000	147	1,050	23.55	82.9
Shell + Radiation Loss	-	-	-	2	7.0
Total				28.4	100

* Reference state 60°F.

** Equivalent to 20% excess air and a process gas containing 4% O_2.

TABLE 4.3-3B

PRE-HEAT FURNACE WITH RECYCLE GAS BALANCE*

Materials	lb/h	BTU/lb	°F	MMBTU/h	% Input
Input					
Natural Gas (HHV)	-			13.0	30.8
Steel Feed	160,000	90	700	14.4	34.1
Air			60	0	
Recycle Gases			1,120	14.8	35.1
Total				42.2	100
Output					
Combustion Gases	4,871		1,050	1.5	3.6
Recycle Gases	52,000		1,050	13.85	32.8
Evap. H_2O				1.3	3.1
Steel Out	160,000	181	1,050	23.55	55.8
Shell + Radiation Loss	-	-	-	2	4.7
Total				42.2	100

* Reference state 60°F.

APPENDIX IV

OFF-GAS COMPOSITION EFFICIENCY CALCULATION EXAMPLE

APPENDIX IV

The off-gas composition method ([1]) for calculating the thermal efficiency([4]) of the pre-heat furnace is summarized as follows:

Dry gas loss (550°F flue 700 % air)	68.4 %
Hydrogen loss	12.0 %
Shell and Radiation Loss	9.5 %
Total Losses	89.9 %

The apparent heating efficiency is 10.1 percent based on the above. This technique does not take into account the way in which tramp air enters the furnaces. In the cases studied, the flue gas exits at floor level while the steel being heated moves through the furnace on a walking beam assembly mid-height in the freeboard. The segregation of tramp air yields a higher thermal efficiency than would be expected based on the flue gas composition alone.